Reel Lesson 6N— COILS *and* CAPACITORS

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6N

COILS AND CAPACITORS

THE THREE CIRCUIT PROPERTIES that influence and control the current for a given applied voltage are **resistance, inductance,** and **capacitance.** When carrying current, resistance causes a voltage drop and dissipates energy which is given off in the form of heat. Much like resistance, inductance and capacitance cause voltage drops, but differ in that their actions do not dissipate energy. The scenes of this reel illustrate the inductive and capacitive actions when changes of current occur.

Scene 1

A MAGNETIC FIELD IS SET UP AROUND A WIRE WHICH IS CARRYING CURRENT

INDUCTANCE is due to the magnetic effect of an electric current, therefore, as a brief review, several scenes of the earlier "Electromagnets" Reel are repeated here.

1A – To begin the review, we show a length of conductor and with no current in it, there is no magnetic field around it.

1B – As soon as it carries current (indicated by the moving rectangles), a magnetic field forms around the conductor. This magnetic field is indicated in the form of circles, all of which have the conductor as a common center.

1C – When the current increases, as indicated by the moving rectangles becoming larger, more circular lines form and the field expands. Then as the current diminishes, the number of lines diminishes, and the magnetic field collapses partially.

1D – If you could view the conductor from the end, as is shown in this scene, you would see more easily how the flux lines all surround or encircle the conductor which forms the common center. As the action is the same for the entire length of the conductor, the complete magnetic field is in the form of a cylinder or tube, the diameter of which varies with the current in the conductor.

Scene 2

ACTING SOMEWHAT IN REVERSE, AN EMF IS INDUCED IN A WIRE WHEN IT CUTS MAGNETIC FLUX LINES

2A – THE WIRE in the former scene is moved to the upper right, and with no current in it, the electrons are distributed uniformly so that the atoms are electrically neutral. This condition is indicated by the spacing of the small white circles in the wire.

Next a magnetic field is introduced with the S pole in the top and the N pole on the bottom. You can think of these poles as the ends of a large U shaped magnet, but our interest is in the magnetic field or lines of force between them.

By means of mechanical energy or force, the wire is moved through the magnetic field from right to left. In the former scene, an electric voltage caused electrons to move through the wire and a magnetic field was set up. Here, the wire, and its electrons are moved mechanically to cut through an existing magnetic field. This combination of motion and magnetic lines of forces causes the electrons in the wire to move.

Stop the projector once or twice as the wire cuts through the magnetic field and notice how the lines of force bend and are compressed in front of it. Notice also, that the electrons in the wire shift toward the front of the picture.

As a result of the influence of the magnetic lines, there is a redistribution of the electrons as the wire is moved. They shift toward and accumulate at the near end of the wire, building up a negative charge. Consequently there is a lack of electrons (less than the normal number) at the far end of the wire, which becomes charged positively.

In other words, the motion of the wire through the magnetic field causes a displacement of the electrons within the wire, and the resulting charges produce a difference of potential or voltage between the ends of the wire.

Scene 3

THE SAME ACTION OCCURS WHEN THE FLUX IS MOVED PAST A STATIONARY WIRE

ALL MOTION IS RELATIVE. For example, if you are sitting in a slowly moving passenger train and looking out of the window at another train on an adjacent track, it is difficult, in fact impossible, to tell whether your train is standing still and the other train is moving forward, or whether the other train is standing still and your train is moving backward. The effects are the same in either case.

3A – In the previous scene you saw the effects of moving a wire from right to left through a stationary magnetic field. Here in Scene 3A you see the same conductor and the same magnetic field, but now the conductor is stationary and the magnetic field is moved from left to right. Again, a redistribution of electrons takes place—an excess number accumulating at the near end of the wire while a corresponding shortage appears at the far end.

When the conductor is in the middle of the magnetic field, stop your projector a few moments and examine the picture. Is there any difference now as to whether the conductor is moving from right to left through a stationary field, or the field is moving from left to right across a stationary conductor? In each case, the wire or conductor cuts the flux lines in the same direction. Consequently the electron displacement in each case also is the same.

The difference of potential between the ends of the wire, produced by the charges caused by the displacement of the electrons while the wire is cutting through the magnetic flux lines, is like the emf produced by the chemical action in a cell or battery. Therefore, an emf is induced in a wire when it cuts through magnetic lines of force. Remember, the action occurs only while the wire is cutting, or is cut by, the magnetic lines.

Scene 4

THE RELATIONSHIP BETWEEN THE DIRECTION OF THE FLUX, THE DIRECTION OF MOTION, AND THE POLARITY OF THE INDUCED EMF, CAN BE SHOWN BY THE THREE-FINGER LEFT-HAND RULE

4A – AGAIN THE FLUX lines are between the magnetic poles with the wire cutting through from right to left at right angles to the lines. You also see the thumb and first two fingers of the left hand stretched out at right angles to each other.

4B – According to the three-finger rule, THE FOREFINGER POINTS IN THE DIRECTION OF THE MAGNETIC LINES, THAT IS, TOWARD THE SOUTH POLE, WHICH IN THIS PICTURE IS VERTICALLY UPWARD.

4C – THE THUMB POINTS IN THE DIRECTION IN WHICH THE WIRE CUTS THE FLUX LINES, in this case from right to left.

4D – THE MIDDLE FINGER, as shown here, THEN POINTS IN THE DIRECTION OF THE INDUCTION, that is, toward the negative. In this scene, it is out of the picture toward you.

Therefore, the near end of the wire is electrically negative, while the far end is positive. This agrees with the previous scenes, for due to the resulting electron displacement, there are less than the normal number of electrons at the far end and an excess number at the near end.

Scene 5

WHEN THE CURRENT IN IT INCREASES, THE WIRE IS CUT BY THE EXPANDING FLUX LINES

THE CIRCULAR MAGNETIC flux lines start at the very center of the conductor and expand outward when a current is set up within a conductor. In like manner, when the current decreases, the magnetic field collapses and the lines shrink and some of them disappear at the center. These are two important concepts to keep in mind, for they help in explaining many of the phenomena that will appear in future pictures.

5A – Repeating a part of Scene 1, here the conducting wire is lying in a horizontal position and pointing away from you to obtain an end view.

5B – Assuming it to be part of a complete circuit, current is then set up in the conductor as is indicated by the rectangles moving toward the near end and toward you.

5C – As soon as the current starts, the magnetic lines also form and encircle the conductor. As the lines form at the center and expand, they cut the body of the conductor from the center to the outer surface, and in doing so, induce an emf as explained previously.

Again, as illustrated in preceding scenes, the magnetic field expands with an increase of current.

Also note particularly that, with constant current there is no change in the flux lines, therefore, there is no cutting and no induction.

Scene 6

WHEN THE CURRENT DECREASES, THE WIRE IS CUT IN THE OPPOSITE DIRECTION BY THE COLLAPSING FLUX LINES

THE MAGNETIC LINES originate at the center of the conductor and expand outward as the current increases. Also, as the current decreases, the lines collapse and disappear at its center.

6A – In this scene, the conducting wire appears once more, with current still in a direction toward you and the flux lines encircling it in a clockwise direction. As the current diminishes, these flux lines collapse, and finally disappear within the conductor.

Scene 7

THE INDUCED EMF IS ALWAYS IN A DIRECTION TO OPPOSE A CHANGE

A CHANGE OF CURRENT in the wire causes the magnetic flux lines to expand or collapse. They cut through the wire and induce an emf by the action illustrated in Scene 3 of this Reel. The direction of this induced emf can be determined by the three finger left hand rule, but before telling you how this is done we want you to view Scene 7.

7A – Here, the assumed direction is from negative to positive and the intensity of the current is indicated by the size of the moving rectangles inside the wire. Notice once more how an increase of current causes the magnetic flux to expand while a decrease of current causes the flux to contract or collapse. Regardless of its intensity, with no change in the current there is no change in the magnetic flux, therefore, there is no cutting and no induction.

As the action is the same all around the wire, to apply the left hand three finger rule, we will consider only a small section between the center of the wire and the top of the screen. With the magnetic flux clockwise around the wire at the top of the screen, its direction is from left to right. When the current increases, the magnetic flux moves outward so that the direction of cutting is the same as if the wire moved inward. Therefore, the direction of cutting is from the top toward the bottom of the screen.

To apply the rule, hold your left hand with the palm outward, forefinger pointing right and thumb down. Your middle finger then will point away from you or in a direction opposite that of the current. Thus, the induced emf is in a direction to oppose the increase of current.

When the current reduces, the flux collapses and the direction of cutting is reversed. Therefore, turn your left hand over so that the thumb points up and your middle finger will point toward you in the direction of the current. Thus, the induced emf is in a direction to maintain the current and oppose the decrease.

Scene 8

THIS ACTION IS INCREASED IN A COIL BECAUSE THE FLUX AROUND EACH TURN CUTS THE WIRE IN ADJACENT TURNS

IN THE VARIOUS COILS used in radio, television, and other electronic circuits, the turns of wire lie close to each other. When a variable current exists in any one of the turns, the expanding and collapsing flux lines surrounding it are intercepted by all the other adjacent turns, with the result that induction occurs in each one of them. This induction, due to the influence of the current-carrying turn, then interferes not only with the current in the original turn, but also with the current in all the other turns.

8A – In this scene you see a coil of five turns wound around an iron core. When the current exists in the coil, a magnetic field is set up in and around the coil. Theoretically this field extends outward indefinitely, but it soon becomes so weak that its effects are imperceptible.

Scene 9

OCCURRING IN A SIMPLE CIRCUIT, THIS ACTION IS KNOWN AS SELF-INDUCTION

INDUCTION OCCURS within the operating coil itself; and when the magnetic lines due to the current in any one turn intercept all the other turns in the same coil, the action is known as self-induction.

9A – Here you see the coil that appeared in the previous scene, but now the current is increasing and decreasing in intensity, as is indicated by the changing size of the moving rectangles in the wire. As a result of this varying current, the strength of the magnetic field fluctuates accordingly.

Scene 10

THIS PROPERTY OF A CIRCUIT WHICH BY SELF-INDUCTION TRIES TO PREVENT A CHANGE OF CURRENT IS KNOWN AS SELF-INDUCTANCE

BETWEEN INDUCTION AND INDUCTANCE, there is an important distinction. Induction is the action by which an emf is induced within a coil or circuit, while inductance is the property or characteristic of a circuit which makes induction possible. Inductance is due purely to the physical arrangement or position of the wires in a coil or circuit.

10A – Once more you see the coil with the variable current through its windings. As the current increases and decreases, the magnetic field fluctuates accordingly, that is, it alternately expands and collapses.

10B – Then a second coil is wound on the same iron core, and placed so that it lies in the magnetic field of the first coil.

10C – As the current through the first coil develops a magnetic field that extends out into space, the expanding flux lines cut the turns of the second coil and induce an emf in them. When the lines shrink with a decreasing current, they cut the same turns and again induce a voltage in them, but this time in the opposite direction. The result is that the second coil intercepts a variable magnetic flux that fluctuates at every instant according to the changes of current in the first coil.

The induced emf is a source of voltage, and when an external circuit is provided, will cause current in the second coil.

Scene 11

BECAUSE THE COILS ARE NOT ELECTRICALLY CONNECTED, THIS ACTION IS KNOWN AS "MUTUAL INDUCTION"

MUTUAL INDUCTION is the inductive action that occurs between two coils that are arranged or placed with respect to each other so that one coil falls within the magnetic influence of the other. The term mutual is applied because not only can the first coil influence the second, but the second can influence the first, that is, the influence is mutual between the two coils.

11A – Mutual induction, or mutual influence, is clearly illustrated in this case, for a variable current in one coil causes the generation of a correspondingly changing emf in the other.

11B – With two coils or circuits arranged as you see them in this scene, they are said to have mutual inductance. This means that not only can the first coil influence the effective inductance of the second, but by the same token, the second can influence the first.

11C – In order that this magnetic influence in coils can be compared or measured, a suitable unit is necessary.

The common unit of inductance measurement is the **henry** named after Joseph Henry, the great American scientist. By definition, A CIRCUIT HAS AN INDUCTANCE OF ONE HENRY IF IT INDUCES AN EMF OF ONE VOLT WHEN THE CURRENT CHANGES AT THE RATE OF ONE AMPERE PER SECOND.

Scene 12

CAPACITANCE

ANOTHER PROPERTY, CAPACITANCE, OPPOSES ANY CHANGE OF VOLTAGE IN A CIRCUIT

IT WAS EXPLAINED in the early part of this reel that there are three factors or properties associated with every electric circuit. The first two of these, resistance and inductance, have been described, and for the remainder of this reel capacitance, the third property, will be illustrated.

12A – Here you see an entirely different type of circuit. Two parallel metal plates, shown at the right, are connected through a simple knife switch across the terminals of a battery.

The two conducting plates, separated by an insulator, constitute the simplest form of a condenser or **capacitor.** A capacitor thus consists essentially of three parts, two adjacent metal **plates** and a separating insulator known as the **dielectric.**

12B – Although the dielectric forms a "break" in the circuit, when the switch is closed there is a momentary current which charges the capacitor. This is known commonly as a charging displacement current and it carries energy from the source to the capacitor. The battery voltage forces electrons from its negative terminal to the capacitor plate to which it is connected. Since like charges repel, the excess electrons of this plate force a like number off the other plate. Thus, there is a momentary current in one plate and out of the other but not through the capacitor.

12C – The energy of the charge appears as a difference in potential between the capacitor plates, a condition which, in this scene, is indicated by the difference in shading of the plates. Electrically, the voltage across a charged condenser is equal to that of the battery or other supply.

12D – When the circuit switch is opened the capacitor retains its charge as indicated here by the upper plate still being darkly shaded, while the lower one is bright.

12E – When a suitable path is provided, the capacitor discharges. In this scene, a resistor is connected between the upper capacitor plate and an added contact on the switch. When the switch blade is moved to this added contact, the excess electrons of the upper plate flow through the resistor and switch to the lower plate of the capacitor. As this discharge continues, the potential difference between the plates is reduced gradually as indicated by the lighter shading of the upper plate.

The discharge or displacement current continues until both plates have equal potential, and the capacitor is in its initial discharged or neutral condition.

Scene 13

THE ACTION HERE IS SIMILAR TO THAT OF A FLEXIBLE DIAPHRAGM IN A CLOSED WATER SYSTEM

A WATER ANALOGY can be used here because the charge and discharge action of a capacitor is similar to that of a flexible diaphragm in a closed water system.

13A – Here we show again the electric circuit with its charging battery, capacitor, discharge path, and the three-position (charge-discharge-open) selector switch. The electric circuit then fades into the corresponding water circuit.

13B – Compared to the electric circuit, for the water circuit the battery is replaced by a cylinder type pump with a movable piston and external connection at each end. The capacitor is replaced by an expansion chamber, divided by a solid, flexible diaphragm. The wires are replaced by pipes. The piston is attached to a shaft which extends through one end of the cylinder to permit the application of external pressure.

13C – When the external pressure moves the piston to the left, water flows into the upper half of the expansion chamber, forcing the diaphragm down and placing it under a strain. Notice here, the downward movement of the diaphragm causes a flow of water from the lower half of the expansion chamber to the pump cylinder. This corresponds to the charging of a capacitor.

If, at this time, the pipes were closed to prevent the flow of water and the pressure was removed from the pump shaft, the strained diaphragm would maintain the pressure but in a direction opposite to that applied externally to the pump shaft. This condition corresponds to a charged capacitor with no discharge path.

13D – Here, the external pressure is removed from the pump piston and to relieve the strain on it, the diaphragm moves back to its original position. This movement of the diaphragm causes a reverse flow of water in the pipes to force the piston back to its former position. The action corresponds to the discharge of a capacitor.

Scene 14

WHEN CONNECTED IN PARALLEL, EACH CAPACITOR HAS FULL SUPPLY VOLTAGE ACROSS IT

CAPACITORS IN PARALLEL are like resistors to the extent that the voltage distribution principles that apply to parallel-connected resistors also apply to parallel-grouped capacitors.

14A – Here you see the original battery-capacitor circuit that was employed previously but now there are two capacitors connected in parallel (in shunt) with each other. Also, the operating switch can be thrown into either the charge or discharge position.

14B – As soon as the switch is thrown into the charging position, there is a displacement current in the circuit. At the junction between the two capacitors, the current divides, and part enters each capacitor. Therefore, the two capacitors become charged, as indicated by the upper plates being shaded more darkly.

As in any parallel circuit the full supply voltage is impressed across each branch and the total current is equal to the sum of the branch currents. Thus, as each capacitor is charged to the full supply voltage, THE TOTAL CAPACITANCE OF PARALLEL-CONNECTED CAPACITORS IS EQUAL TO THE SUM OF THEIR SEPARATE CAPACITANCES.

Scene 15

WHEN CONNECTED IN SERIES, EACH CAPACITOR HAS BUT A PART OF THE SUPPLY VOLTAGE ACROSS IT

CAPACITORS CAN BE CONNECTED in series also, and when arranged in this manner, the charging current is the same for all, but each capacitor will receive only a part of the total applied voltage.

15A – Here, the original battery-capacitor circuit is shown once more, except that now two capacitors are connected in series across the battery or voltage supply.

15B – Again a water circuit will be used for comparison because the action is similar to that of series connected diaphragms in a closed water system.

15C – For simplicity, here we show only the two series connected expansion chambers of a water circuit like that of Scene 13. As the external pressure moves the pump piston and forces water into the upper pipe, the diaphragm of the upper chamber is bent down, thereby forcing water into the upper part of the lower chamber. This causes the lower diaphragm to bend and force water back toward the pump.

Thus, the total pressure produced by the pump is absorbed partially by each diaphragm but the flow of water is the same in both the upper and lower pipes.

When the external pressure is removed, the diaphragms spring back to the normal position and in doing so, cause a reverse flow of water.

15D – As the external pressure is applied again, both diaphragms bend, but straighten as the pressure is removed. Thus, the action is similar to that of a single expansion chamber but each diaphragm absorbs part of the total applied pressure.

15E – Back to the electric circuit, when the switch is closed the charging current is present in both capacitors much like the water in the preceding scene. As indicated by the degree of shading on the plates, each capacitor is charged to a portion of the supply voltage and like other series connections, the charging or displacement current is the same in all parts of the circuit.

The important point for you to remember about series connected capacitors is: THE TOTAL CAPACITANCE OF TWO SERIES CONNECTED CAPACITORS IS EQUAL TO THE PRODUCT OF THEIR SEPARATE CAPACITANCES DIVIDED BY THEIR SUM.

Scene 16

FOR BOTH INDUCTANCE AND CAPACITANCE, ACTIONS OCCUR ONLY WHILE THE CIRCUIT CURRENT OR VOLTAGE VALUES ARE CHANGING

THE EFFECT OF RESISTANCE is present at all times, but *inductance and capacitance manifest themselves only under changing or variable circuit conditions.* While they are present at all times, their effects are noticeable only when a change occurs.